Biological Evaluation
Of
Hemlock Woolly Adelgid
At
Morristown National Historic Park, New Jersey Brigade,
Cross Estates
Morristown, New Jersey

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ABSTRACT

In the summer of 2004, USDA Forest Service personnel conducted surveys to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae* and the elongate hemlock scale (EHS) *Fiorina externa* populations at Morristown National Historic Park (MNHP) New Jersey Brigade, Cross Estate and to assess the need for treatment.

INTRODUCTION

HEMLOCK WOOLLY ADELGID

Adelgids are small, soft-bodied insects that feed on plant sap. The family is divided into two genera: *Adelges* and *Pineus*. The members of this family feed exclusively on conifers. There are six species of *Adelges* that occur in North America, of which only one is native (Montgomery 1999), the Cooley spruce gall aphid (*Adelges cooleyi*). This adelgid occurs coast to coast in northern North America. Its primary hosts are recorded as white (*Picea glauca*), blue (*Picea pungens*), Sitka (*Picea sitchensis*), and Engelmann (*Picea engelmannii*) spruce (Baker 1972). It has an alternate host, Douglas fir (*Pseudotsuga menziesii*). There are 10 species of *Pineus* that occur in North America, of which seven are native. Four of these the pine bark adelgid (*Pineus strobi*); the pine leaf adelgid (*P. pinifoliae)*; the red spruce adelgid (*P. floccus*); and the spruce gall adelgid (*P. similes*) seem to be indigenous to eastern North America (Drooz 1989, Montgomery 1999). These species attack eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) but seldom cause extensive damage (Drooz 1989, Montgomery 1999). Little is known about the population dynamics, ecological role, or the predator and parasite complex associated with these native adelgids.

Native to Asia, the hemlock woolly adelgid (*Adelges tsugae)*, is a pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliana*) (Onken et al. 1999) both of which are considered highly susceptible to the adelgid, with no documented resistance (Bentz et al. 2002). The latter tree species is found only in the southern region of the Appalachian Mountains (Onken et al. 1999). The HWA is currently established in 16 Eastern States from Georgia to Maine, and tree decline and mortality have increased at an accelerated rate since the late 1980s. For example, in the Shenandoah National Park (SNP), hemlock crown health has declined since the early 1990s. In 1990, greater than 77 percent of the hemlocks sampled were in a "healthy" condition; by 1999, less than 10 percent were in a "healthy" condition (Akerson and Hunt 1998). In another study at SNP, tree mortality significantly increased from an initial 8 percent in 1990 to nearly 50 percent in 2000 (Bair 2002). In New Jersey less than 13 percent of stands surveyed in 1991 remain healthy. Twelve years after initial HWA infestations, tree mortality has reached more than 90% in some New Jersey hemlock stands (Mayer et al 2002).

The hemlock woolly adelgid is parthenogenetic (an all-female population with asexual reproduction) that has six stages of development: the egg, four nymphal instars, and the adult, and two generations a year on hemlock; each adult adelgid can produce 50 to 300 eggs in her lifetime (McClure 1989, 1995). The hemlock woolly adelgid also has a winged form that is produced by the spring generation. This form must complete part of its life cycle on spruce. The apparent lack of a suitable spruce host for this form in eastern North America results in a substantial loss of adelgids each year (McClure 1992b). Although natural mortality in HWA populations is commonly between 30 to 60 percent (McClure 1989, 1996), the reproduction potential of this insect remains high. Other mortality is generally attributed to two likely causes: 1) an extended period of cold temperatures or rapid

temperature changes that coincides with a susceptible period of development for the adelgid, and/or 2) a sufficient loss in the nutritional quality and quantity of the food source, which is associated with the decline in health and vigor of the host tree (McClure 1996, Onken et al. 1999). Adelgid feeding can kill a mature tree in about 5 to 7 years (McClure et al. 2001). This tiny insect (~ 1 mm) feeds on all life stages of hemlock, from seedling to mature, old growth tree. The first instar nymphs, called crawlers, search for suitable sites at the base of the hemlock needles, and insert their feeding stylets into the young hemlock twigs and are committed to that feeding site throughout the remainder of its development. The stylet bundle is more than three times the length of the insect and penetrates deep within the plant tissues. HWA does not deplete nutrients directly by feeding on the sap, but rather by depleting the food reserves from the tree's storage cells (McClure et al. 2001). Dispersal and movement of HWA during its egg and mobile first instar stages is associated with wind, birds, deer, and other forest dwelling mammals. Humans also move the adelgid during logging and recreational activities and movement of infested nursery stock (McClure 1995). Natural enemies capable of maintaining low-level HWA populations are nonexistent in eastern North America (Van Driesche et al. 1996, Wallace and Hain 1998).

HWA was first reported in the western U.S. in the 1920s (Annand 1924, McClure 2001). HWA populations on western tree species, including western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), appear to be innocuous; these tree species are believed to be resistant because little damage has been reported (McClure 2001). Unfortunately, both these trees are of limited value for hybridization and planting due to their poor adaptation to the east coast environment (Bentz et al. 2002). In the East, HWA was first reported in 1951 near Richmond, Virginia. It was considered to be more of an urban landscape pest and was controlled using a variety of insecticides applied with ground spraying equipment. Observations of the adelgid were periodically reported in several Mid-Atlantic States in the 1960s and 1970s but it was not until the 1980s that HWA populations began to surge and spread northward to New England at an alarming rate. By the late 1980s to early 1990s, infestations of HWA were reported to be causing extensive hemlock decline and tree mortality in hemlock forests throughout the East (McClure 2001).

SCALE INSECTS

There are several scale insects that affect hemlocks in the eastern United States. The more common ones belong to the family *Diaspididae*, or armored scales. Armored scales form a protective cover that is unattached to the body. The hemlock scale, *Abgrallaspis ithacae,* is native to the United States and is probably present throughout the East. *A. ithacae* is generally not a significant pest (Johnson and Lyon 1988). The hemlock scale has also been reported on fir (*Abies* species) and spruce (*Picea* species) (Drooz 1989). Two exotic scales that attack the eastern and Carolina hemlock are the elongate hemlock scale, *Fiorinia externa*, and the short needle evergreen scale (a circular hemlock scale), *Nuculaspis tsugae* (Johnson and Lyon 1988, McClure 2002a). Native to Japan, the short needle evergreen scale and the elongate hemlock scale were first reported in the United States, in 1910 and 1908, respectively. The short needle evergreen scale is now known to occur in Connecticut, Maryland, New Jersey, Rhode Island, and New York (McClure 2002a), and its hosts other than hemlock include fir, cedar (*Cedrus* species), spruce and yew (*Taxus* species) (Drooz 1989). The EHS has been found in the District of Columbia and in nine states from Virginia to southern New England and west to Ohio (McClure 2002b). The EHS is known to occur on species of spruce, fir, yew and hemlock (Drooz 1989). Spruce and fir tend to be even more susceptible than hemlock, although it has not yet spread into the natural ranges of these other native conifers. Circular hemlock scale is far less abundant and generally out competed by the elongate hemlock scale (McClure 2002a).

The EHS completes two generations each year in the Southern and Mid-Atlantic States, but usually only one in the Northeast. Its life stages are broadly overlapping everywhere, and crawlers can be found throughout the spring and summer. Crawlers are the only stage capable of dispersing and establishing new infestations. Dispersal between trees is primarily by wind and birds. Females have three stages of development after the egg stage, while males have five. During the first and second instar stages, both sexes settle beneath the thin waxy cuticle on the lower surface of the youngest hemlock needles and begin to feed. While in these stages, both sexes secrete a cover around itself as it grows. After the first and second nymphal instar stages, the female then molts into the adult feeding stage, while the male molts into a non-feeding prepupa and spins a cocoon, where it pupates before it emerges as an adult. The adult male mates with the female and dies soon thereafter without feeding. The adult female lays about 20 eggs within her cover. The EHS usually overwinters, either as an egg or as an inseminated adult female. When the crawlers hatch, they exit through a small opening at the posterior end of the cover (McClure 2002b).

The EHS attacks the underside of the hemlock needles by removing fluids from the mesophyll cells through piercing and sucking mouthparts. Scale populations build slowly on healthy trees, but much more quickly on stressed ones. Feeding by HWA has been shown to affect nutrient dynamics in hemlock stands (Jenkins et al. 1999) and this could feasibly reduce tree vigor sufficiently to allow scale insects such as EHS to become established and explode in population size (Danoff-Burg and Bird 2002). Mixed infestations of EHS and HWA can greatly hasten hemlock decline. Feeding by EHS causes foliage to turn yellow and drop prematurely. Dieback of major limbs, which usually progresses from the bottom of the tree upwards, usually occurs after scale density reaches about 10 individuals per needle. Trees often die within the next 10 years, but some survive longer in a severely weakened condition with only a sparse amount of foliage at the very top of the crown. These weakened trees have very little chance of recovery and often fall victim to secondary pests, such as hemlock borer and *Armillaria* root disease or readily broken and thrown by wind (McClure 2002b).

HEMLOCK IMPORTANCE

Eastern hemlock is an extremely shade tolerant tree species, capable of surviving for as long as 350 years underneath a shaded forest canopy (Quimby, 1996). It is a slow-growing long-lived tree. It may take 250-300 years to reach maturity and may live for 800 years or more (Godman and Lancaster 1990). Eastern hemlock forests create distinctive microclimates and provide important habitat for a variety of wildlife, such as birds, fish, invertebrates, amphibians, reptiles and mammals. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests at some point during their life (Yamasaki et al. 2000).

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HWA HISTORY AND OTHER STRESSORS AFFECTING HEMLOCK HEALTH CONDITIONS AT MORRISTOWN NATIOANL HISTORIC PARK, CROSS ESATES

Hemlock woolly adelgid (*Adelges tsugae)* and one type of scale (*Fiorinia externa*) have infested the hemlocks that line the Cross Estates driveway. These twenty three trees were treated with horticultural spray oil from 1992 through 1994 using a portable pressurized sprayer. This method did not reach all of the branches of the trees; approximately forty to sixty percent of each tree was reached and sprayed. In 1995 Morristown National Historical Park hired the Sav-A-Tree company to come in and spray the trees with a machine that can reach approximately eighty to ninety percent of the branches. The trees were sprayed twice each year in this manner in 1995, 1996, 1997, and three times in 1998.

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In addition to the trees that line the driveway, hemlocks around the tool shed behind the Cross Estate and on the fire road below the Chalet are also infested with the hemlock woolly adelgid (HWA). The trees near the tool shed have been treated; the trees below the Chalet have not. Many of the hemlocks around the tool shed are in severe decline or dead, though the tree from which the samples were taken looks fairly healthy and has new growth.

Naturally occurring hemlocks in the Mt. Kemble area of the park were visually inspected on July 24, 1998. Very few (less than six) of the trees were still alive. All of these were heavily infested with HWA and had not been previously treated by the park.

METHODS

Twenty two hemlock trees lining the driveway to Cross Estates and two additional hemlocks in a field adjacent to Cross Estates were included in this survey. An assessment of tree vigor, crown position, scale density, and HWA population densities was conducted on each tree.

Tree vigor indicates the health of the tree crown based on the rating below:

Healthy (H) = tree appears to be in reasonably good health: less than 10% branch or twig mortality, discoloration, or dwarfed leaves present
Light Decline (LD) = branch mortality, twig dieback, foliage discoloration, or dwarfed leaves present on 10-25% of the crown
Moderate Decline (MD) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 26-50% of crown
Severe Decline (SD) = more than 75% of the crown with branch mortality, dieback, discoloration or leaf dwarfing, but foliage still present indicating that the tree is alive

Crown position of each hemlock tree was determined based upon the location of the hemlock crown relative to the canopy. Crown position was based on the rating below:

D=dominate, CD=codominate, I=intermediate, S=suppressed

Visual estimate of scale density on needles within a 30 centimeter length of hemlock branch was based upon the following:

Heavy = >1 scale/needle on average
Moderate = 1/needle on average
Light = <1/needle on average
None = not infested

HWA population densities were determined by obtaining a minimum of three 30 centimeter branch samples from each tree. Each branch tip, 2004 new growth only, was visually inspected and the total number of tips, total number of tips with adelgid, and scale density was recorded.

RESULTS

The survey area is represented in Figure 1. The results of the survey are summarized in Tables 1, 2, and 3. Twenty four hemlock trees were included in this survey. At the time of the survey one hemlock tree was dead and five hemlock trees had branches unreachable by hand thus no sample was obtained (tables 1 and 2). A total of 17 hemlock trees were evaluated based upon visual inspection and branch samples taken on site. Sixteen of these hemlocks were codominant in the overstory and one was intermediate.

New (2004) shoot growth and HWA densities varied among the 17 trees sampled. The average number of new shoots was 23 and ranged from 4-50. The average number of shoots with adelgid was 7 and ranged from 2-17 (table 2). Tree vigor ratings ranged from light to moderate decline.

EHS was observed to be at light densities (<1/needle on average) on 16 hemlock trees and moderate density (1/needle on average) on one hemlock (table 1).

Figure 1. Hemlock woolly adelgid survey location at Morristown National Historic Park, New Jersey Brigade, Cross Estates – Summer 2004.

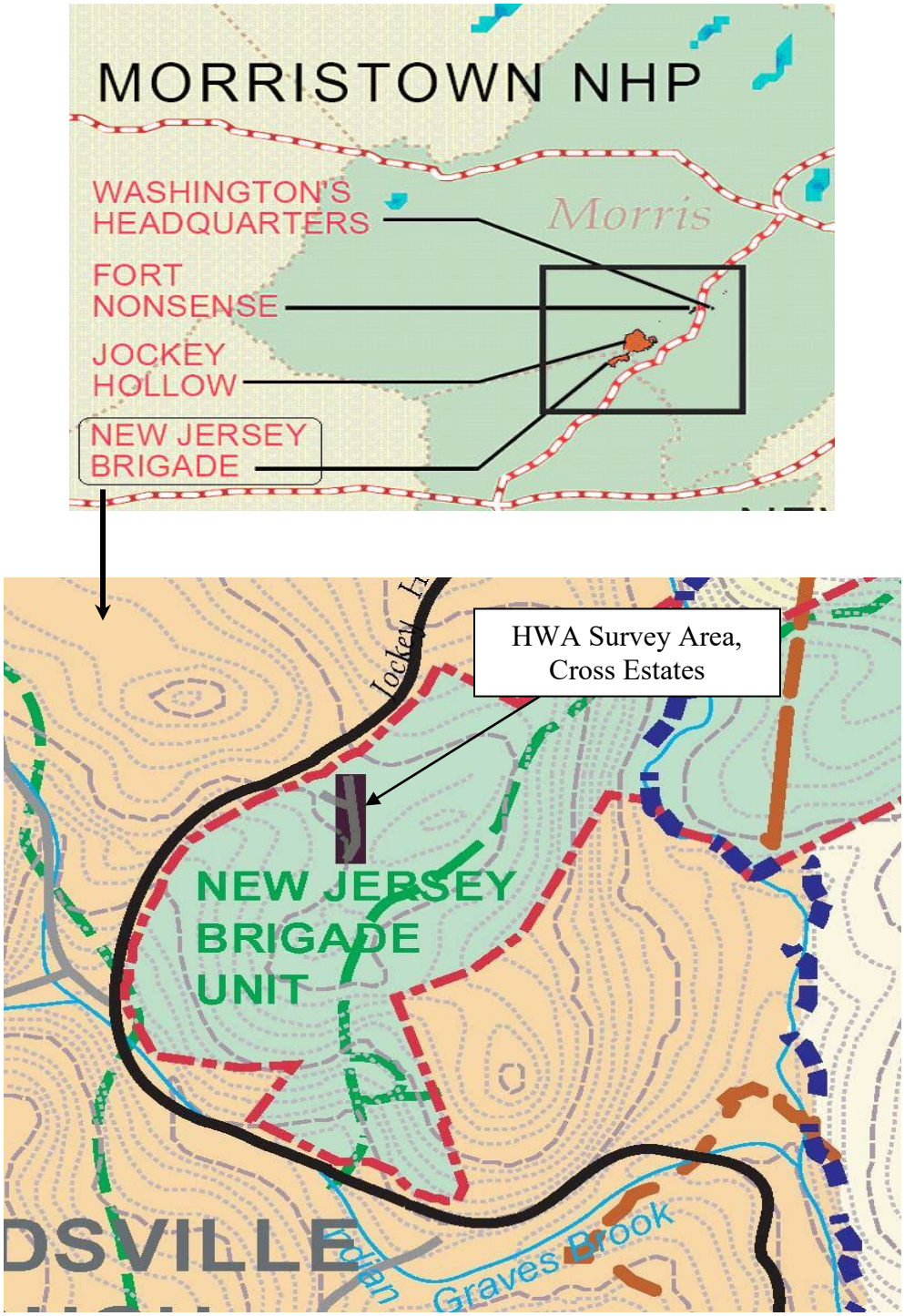

Table 1. *Summary of the hemlock woolly adelgid survey for Morristown National Historic Park, New Jersey Brigade, Cross Estates – Summer 2004.*

TREE #	LOCATION	CROWN POSITION[1]	NUMBER OF SHOOTS[2]	NUMBER OF SHOOTS WITH ADELGID[2]	VIGOR[3]	SCALE DENSITY[4]
1	Cross Estates	CD	50	17	MD	LIGHT
2	Cross Estates	CD	21	4	MD	LIGHT
3	Cross Estates	CD	15	2	LD	LIGHT
4	Cross Estates	CD	34	10	LD	LIGHT
5	Cross Estates	CD	22	6	LD	LIGHT
6	Cross Estates	CD	25	7	LD	LIGHT
7	Cross Estates	CD	36	2	LD	LIGHT
8	Cross Estates	CD	17	9	LD	LIGHT
9	Cross Estates	CD	24	9	LD	LIGHT
10	Cross Estates	CD	33	7	LD	LIGHT
11	Cross Estates	I	29	6	MD	LIGHT
12	Cross Estates	DEAD	--------	--------	--------	--------
13	Cross Estates	NO SAMPLE[5]	--------	--------	--------	--------
14	Cross Estates	CD	15	3	LD	LIGHT
15	Cross Estates	NO SAMPLE[5]	--------	--------	--------	--------
16	Cross Estates	CD	4	4	LD	LIGHT
17	Cross Estates	NO SAMPLE[5]	--------	--------	--------	--------
18	Cross Estates	NO SAMPLE[5]	--------	--------	--------	--------
19	Cross Estates	CD	20	8	LD	MODERATE
20	Cross Estates	CD	6	3	MD	LIGHT
21	Cross Estates	NO SAMPLE[5]	--------	--------	--------	--------
22	Cross Estates	CD	13	6	LD	LIGHT
23	Cross Estates	NO SAMPLE[5]	--------	--------	--------	--------
24	Cross Estates	CD	30	9	LD	LIGHT

[1]-Crown position: D=dominate, CD=codominate, I=intermediate, S=suppressed

[2]-Average of three branch samples per tree

[3]- Vigor = Tree crown health: Healthy (H) = tree appears to be in reasonably good health: less than 10% branch or twig mortality, discoloration, or dwarfed leaves present

Light Decline (LD) = branch mortality, twig dieback, foliage discoloration, or dwarfed leaves present on 10-25% of the crown

Moderate Decline (MD) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 26-50% of crown

Severe Decline (SD) = more than 75% of the crown with branch mortality, dieback, discoloration or leaf dwarfing, but foliage still present indicating that the tree is alive

[4]-Scale presence based on visual estimates from 30 cm length of hemlock branch: HEAVY = (>1/needle on average), MODERATE = (1/needle on average), LIGHT = (<1/needle on average), NONE = (0% infested)

[5]-Tree branches were unreachable by hand, no sample obtained

Table 2. *Summary of maximum and minimum numbers of shoots/ shoots with adelgids and total averages for Morristown National Historic Park, New Jersey Brigade, Cross Estates – Summer 2004.*

MAXIMUM NUMBER OF SHOOTS N=17	MINUMUM NUBER OF SHOOTS N=17	MAXIMUM NUBER OF SHOOTS WITH ADELGID N=17	MINIMUM NUMBER OF SHOOTS WITH ADELGID N=17	TOTAL AVERAGE NUMBER OF SHOOTS N=17	TOTAL AVERAGE NUMBER OF SHOOTS WITH ADELGID N=17
50	4	17	2	23	7

RECOMMENDATIONS

Treatment to control both HWA and EHS using a 2 1/2% solution of horticultural oil on infested hemlocks is recommended. All of the surveyed trees can be easily accessed by truck mounted hydraulic spray equipment that would be necessary to obtain thorough coverage. Treatment timing should co-inside with peak EHS crawler emergence which should be sometime in June in the Morristown area. A second treatment this fall may be necessary if new EHS and or HWA appear on 2005 new growth. Monitoring these pest populations and treating populations before they build to damaging levels is the best way to minimize impacts to hemlock health.

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